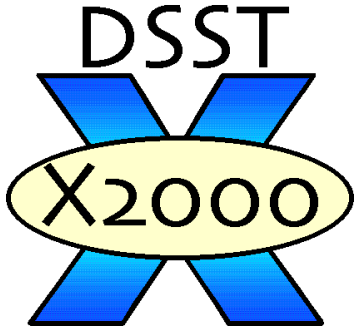
# Introduction to the Deep Space Systems Technology Program (aka X2000)



**Les Deutsch**

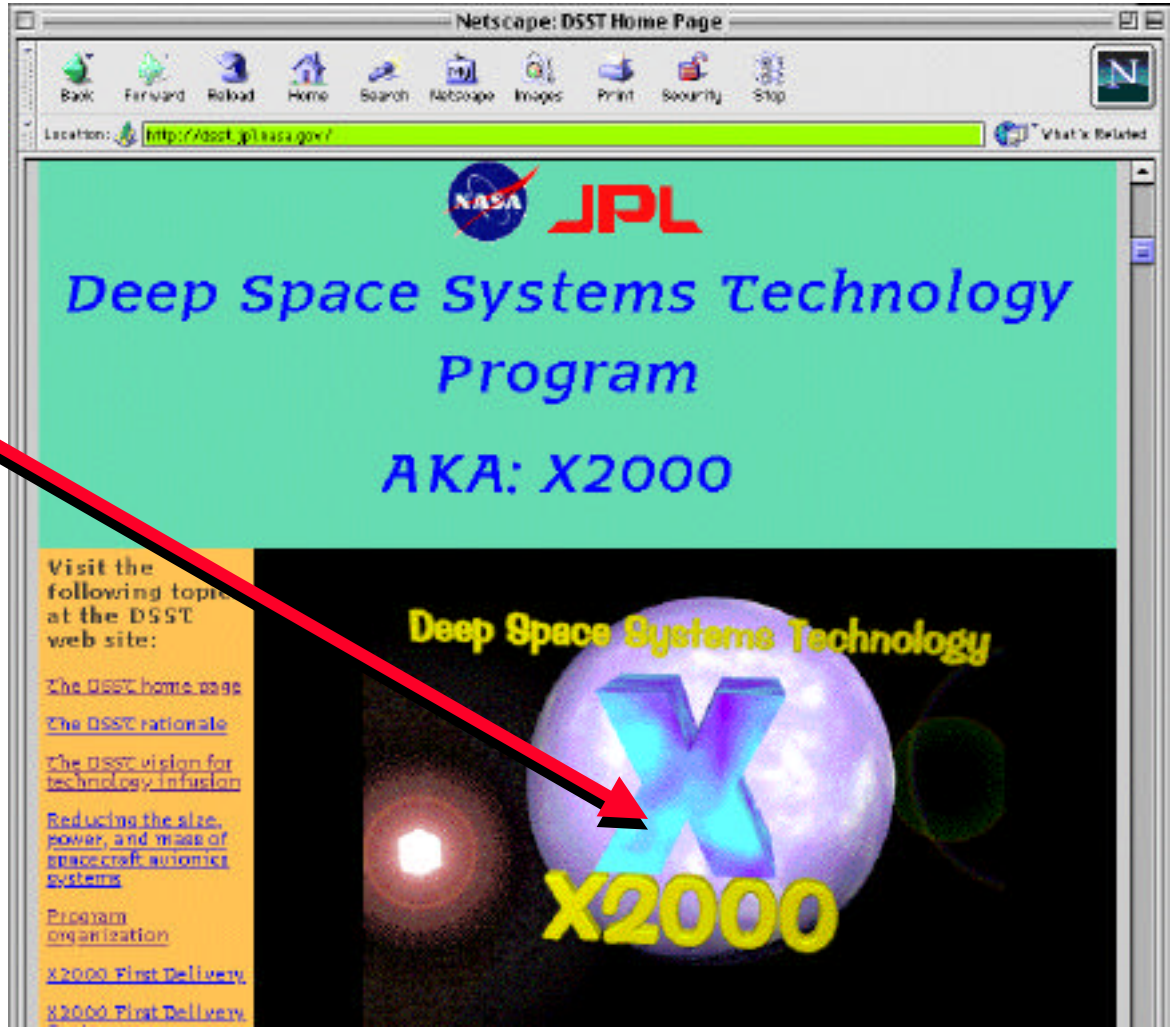
**Manager, Deep Space Systems Technology (DSST) Program**

**April 28, 1999**

# Introduction to X2000

## The DSST Web Page

- Go to the DSST Home Page at http://dsst.jpl.nasa.gov/
- Click on the big logo to go to the internal web site
  - Available only to registered users in the nasa.gov domain



# Introduction to X2000

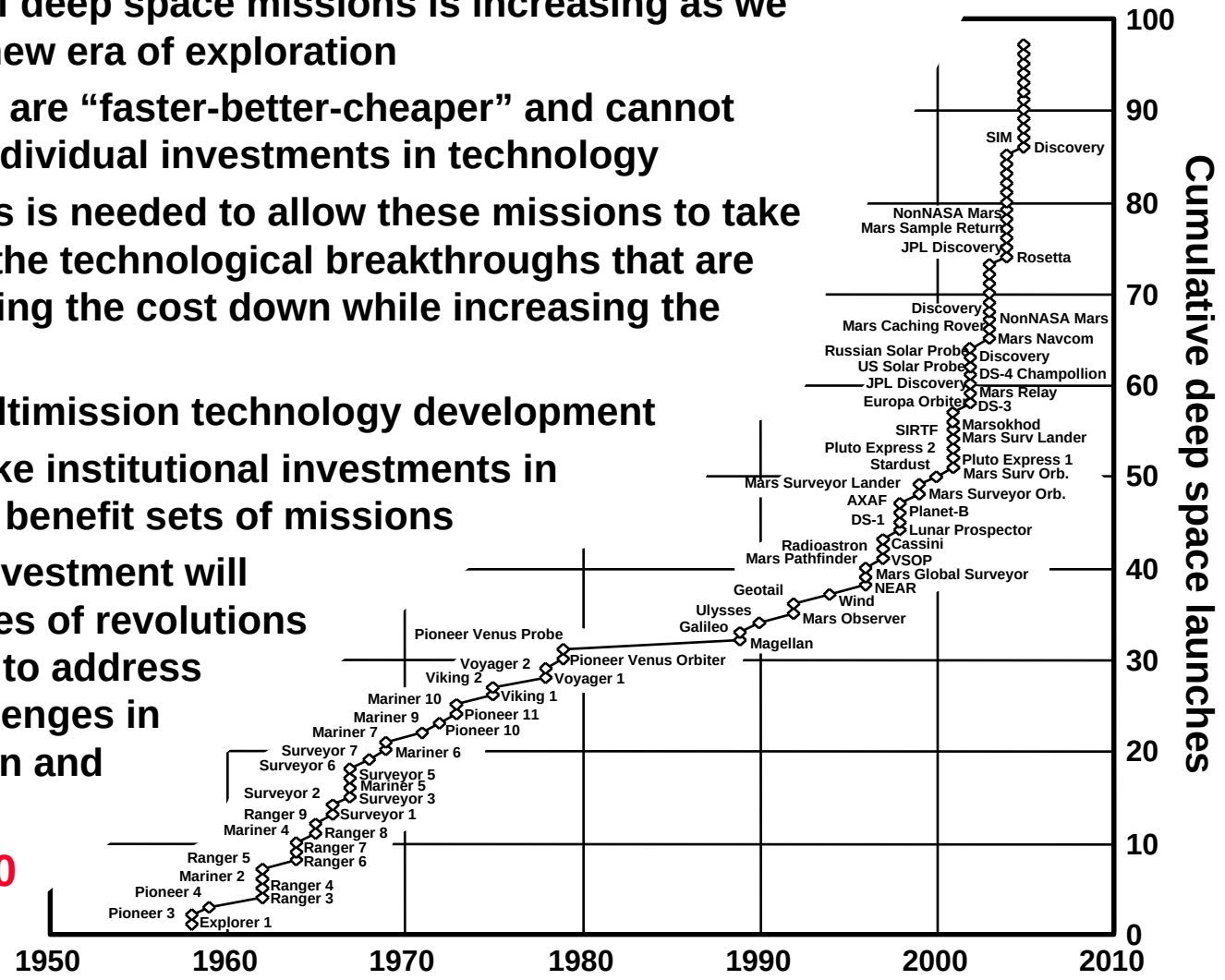
## The Old Days

- Missions were large and expensive
- A new deep space mission “start” occurred only every few years
- Mission budgets were large enough to do substantial technology development
- Technology used on one mission would be obsolete by the next mission

# Introduction to X2000

## The Future

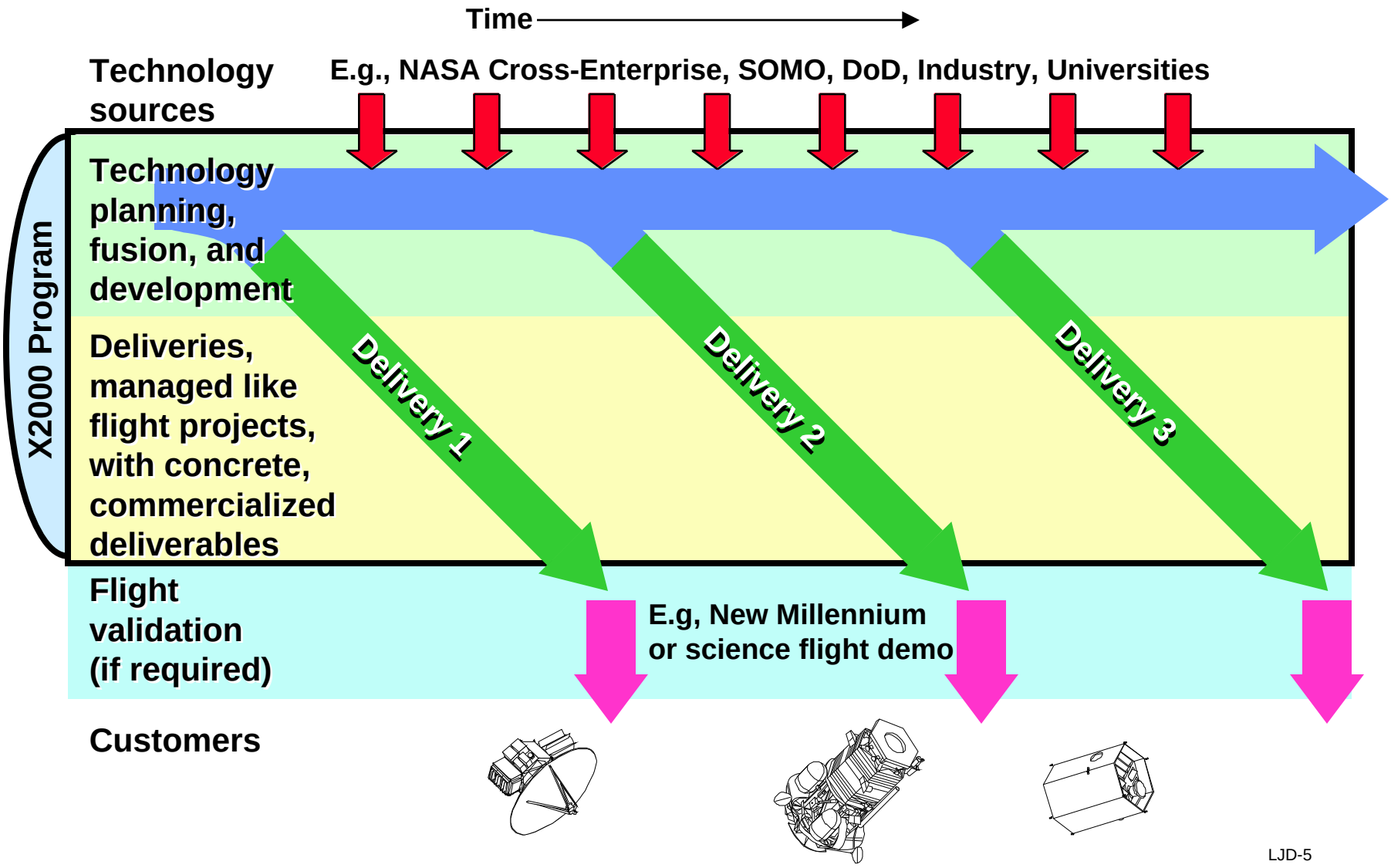
- The number of deep space missions is increasing as we embark on a new era of exploration
- New missions are “faster-better-cheaper” and cannot afford large individual investments in technology
- A new process is needed to allow these missions to take advantage of the technological breakthroughs that are critical to getting the cost down while increasing the science
- The key is multimission technology development
- NASA will make institutional investments in technology to benefit sets of missions
- Continuous investment will provide a series of revolutions in technology to address common challenges in mission design and execution
- This is X2000



The X2000 Program

# Introduction to X2000

## X2000 Concept



# Introduction to X2000

## The Customers of X2000

- X2000 was set up by NASA Code S to enable outer planets missions
- Much of what X2000 develops, however, is of use to a much broader community
  - Other themes within Code S
  - Code Y
  - Code M
- Code S has encouraged us to seek other customers within NASA
- X2000 has a continuing relationship with GSFC including their Nanosatellite Program
- Already, there are customers outside of SSE that have signed up to use X2000 First Delivery capabilities
- We are always looking for ways to better serve the NASA community

# Introduction to X2000

## Technology Development at NASA

New ideas

Breakthroughs

Revised costs

Consortia

Requirements

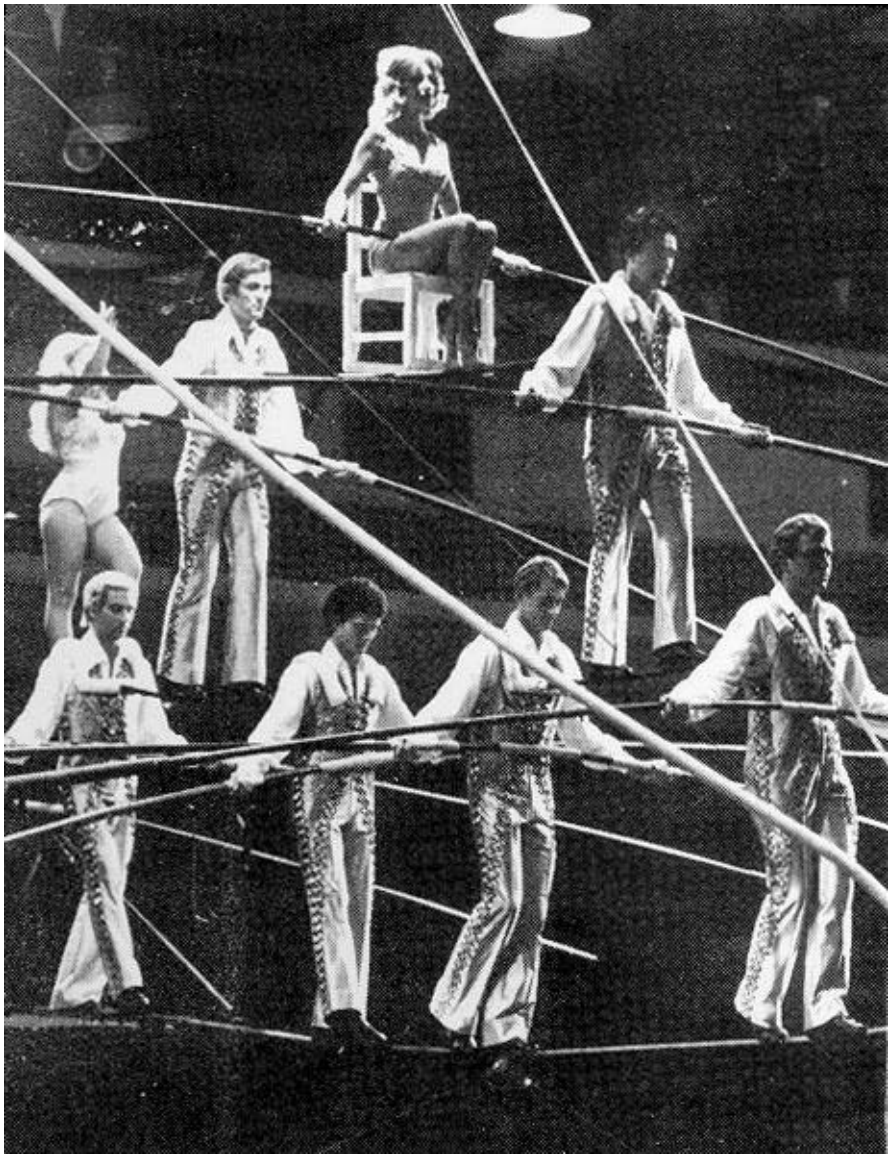
Customer schedule

Risk

Budget raids

# Introduction to X2000

## Technology Development for Multiple Customers



# Introduction to X2000

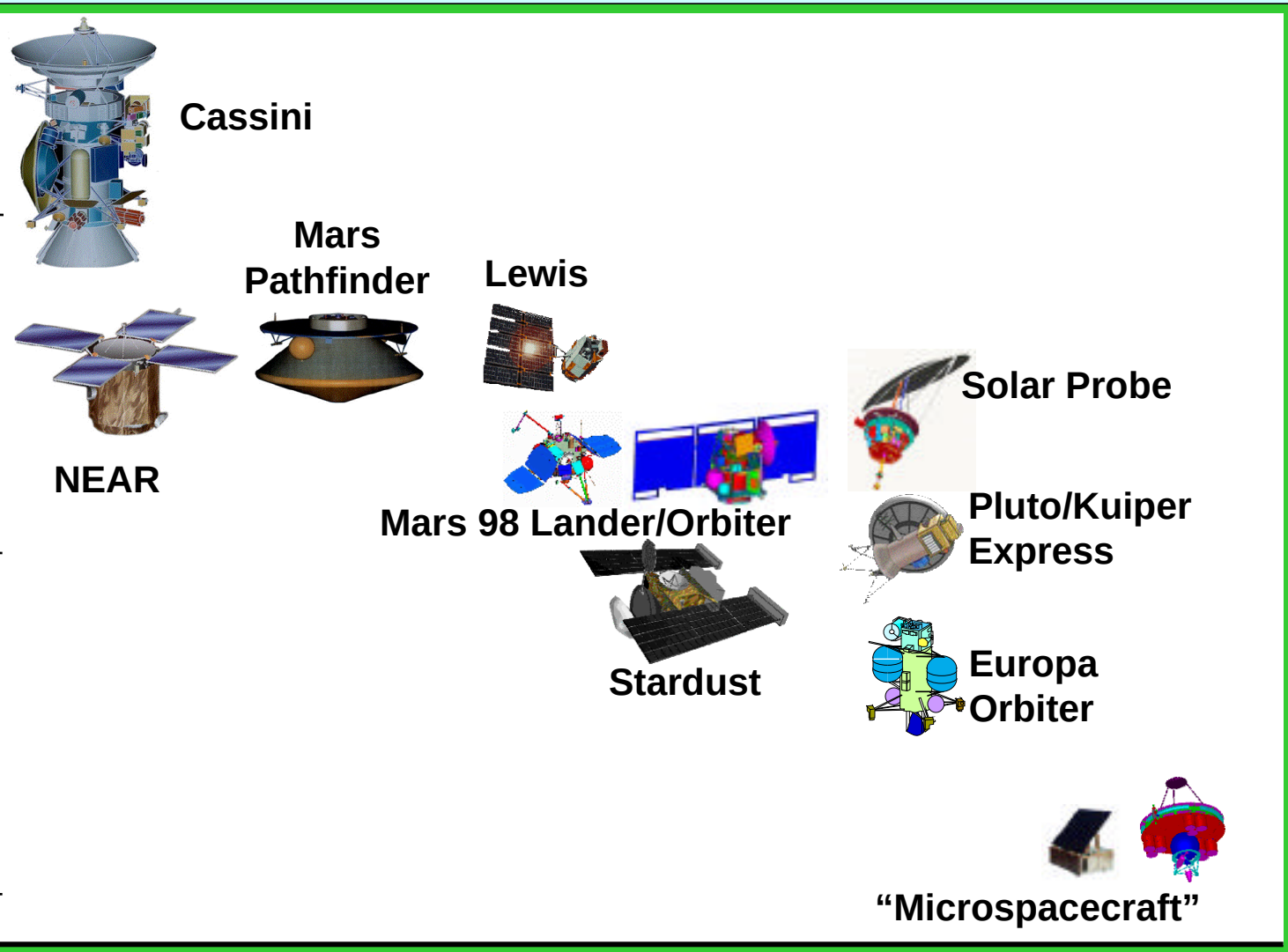
## Getting the Work Done

- X2000 is only successful if the new capabilities are subsequently available through American industry – JPL will not be in the manufacturing business
- Commercialization of all delivered capabilities is critical
- All implementation work on Deliveries is accomplished with industry partners
- Most low TRL work is performed in American universities
- Much work is performed in partnership with other NASA Centers and US Government Agencies

The X2000 Program

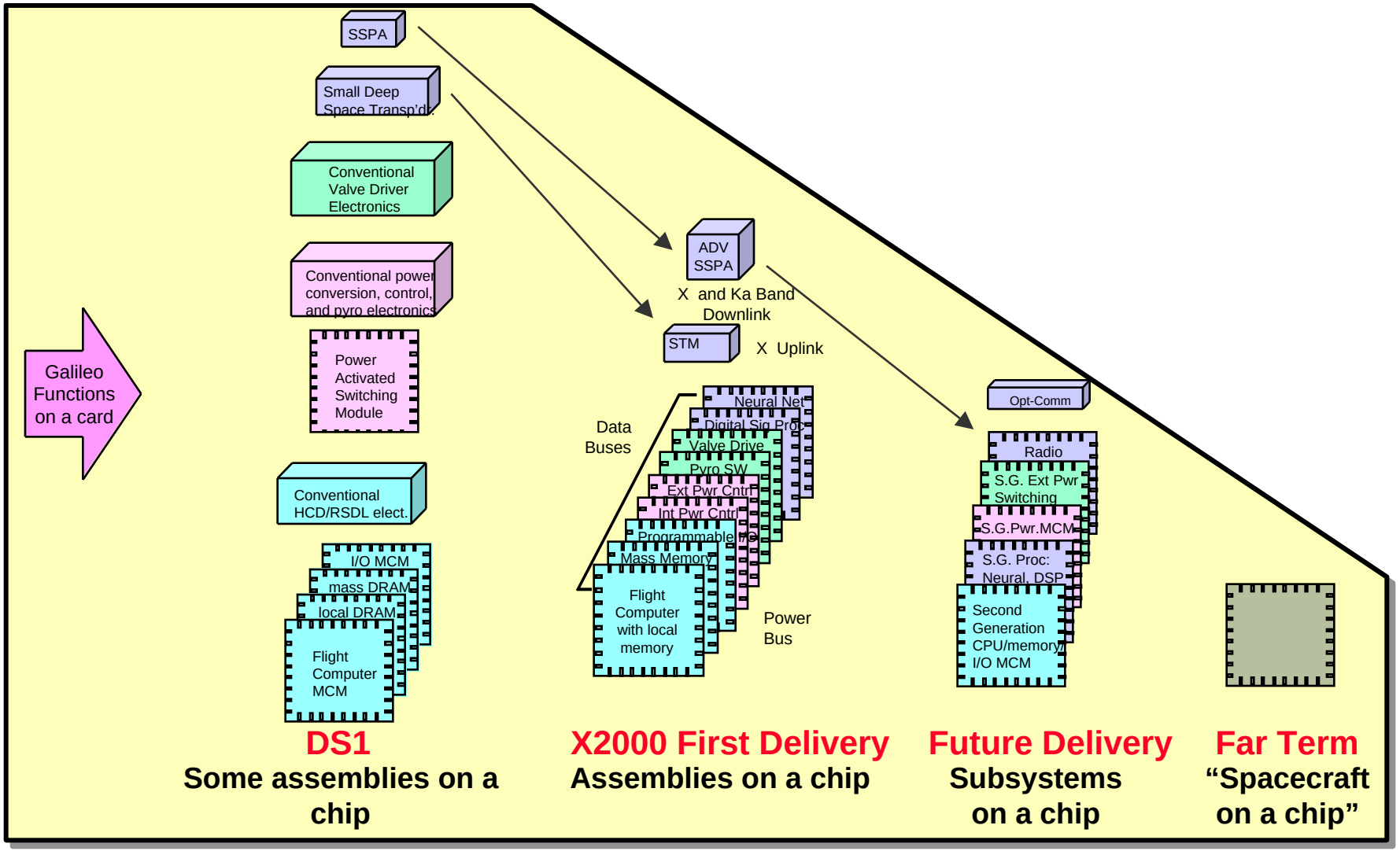
# Introduction to X2000

## The Trend Toward Smaller Spacecraft



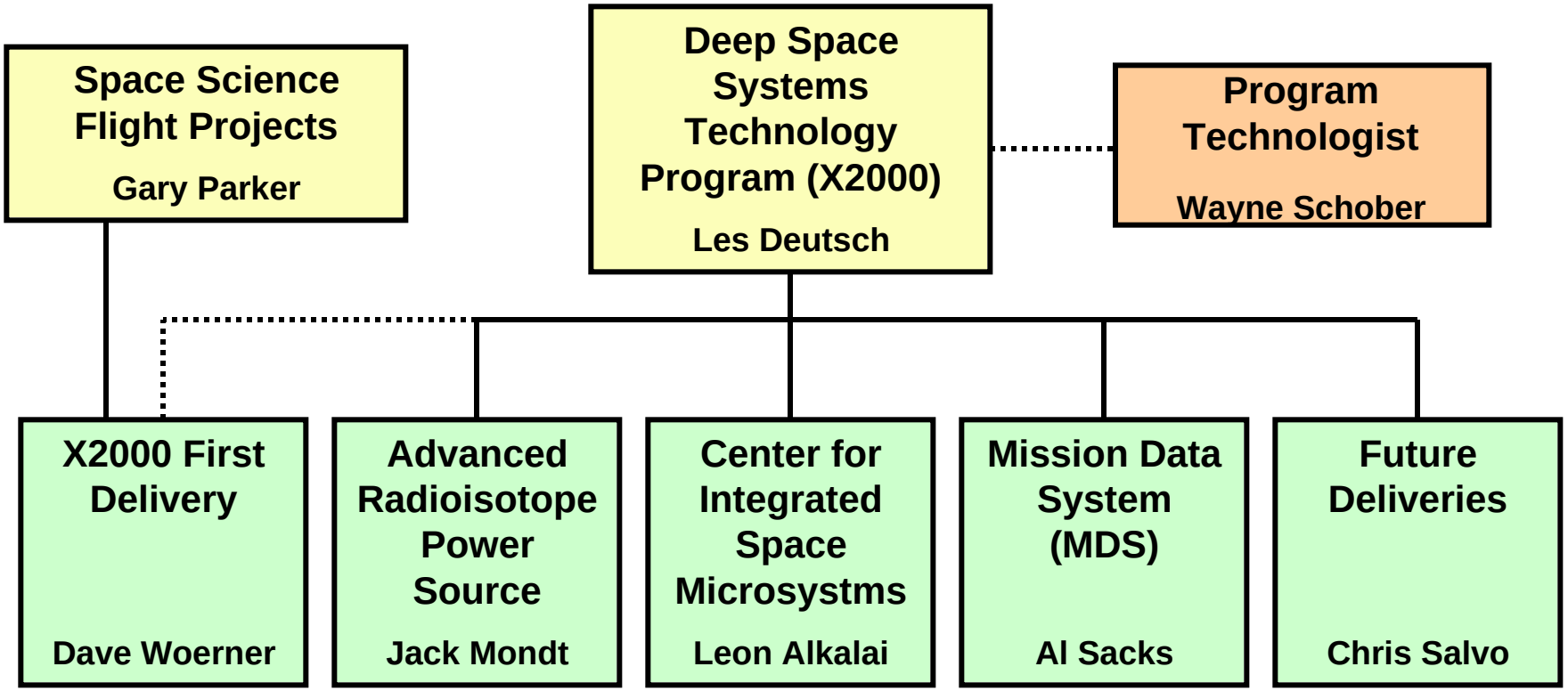
The X2000 Program

# Introduction to X2000
## Avionics Miniaturization



# Introduction to X2000

## Program Top-Level Organization

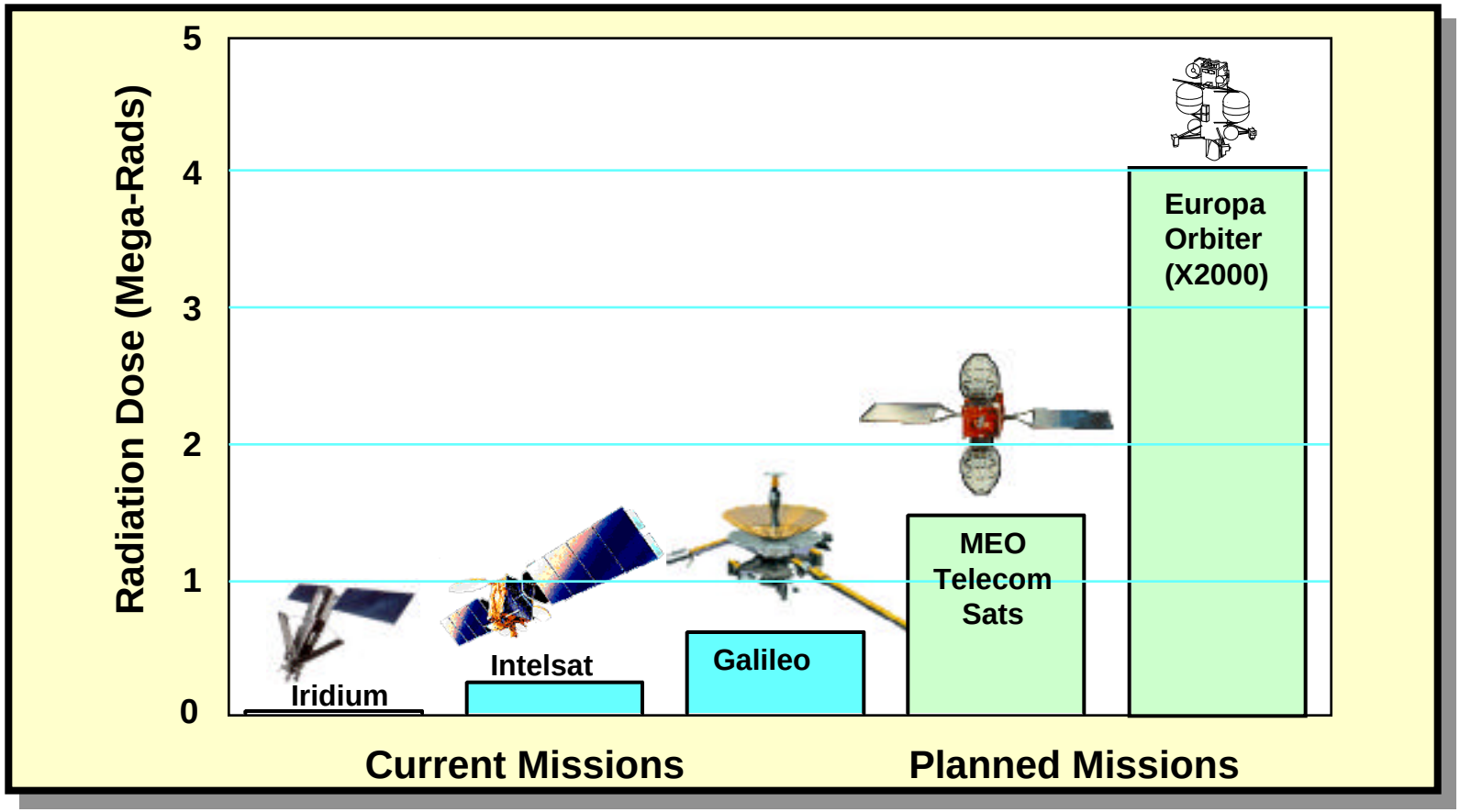



- As X2000 spawns Deliveries, they become projects and are managed in like other SESPD projects
- Other program elements have commitments to deliveries as well as longer-term technology development
- The CISM element shown is programmatic, it is not the JPL Center of Excellence

# Introduction to X2000

## Radiation-hard Delivery

- X2000 First Delivery will deliver radiation-hard capabilities
- Designs and components will also be useful for commercial endeavors
- Design will survive in LEO, GEO, and deep space, and enables MEO missions
- Design will also handle SEUs and will be immune to particle-induced latch-up



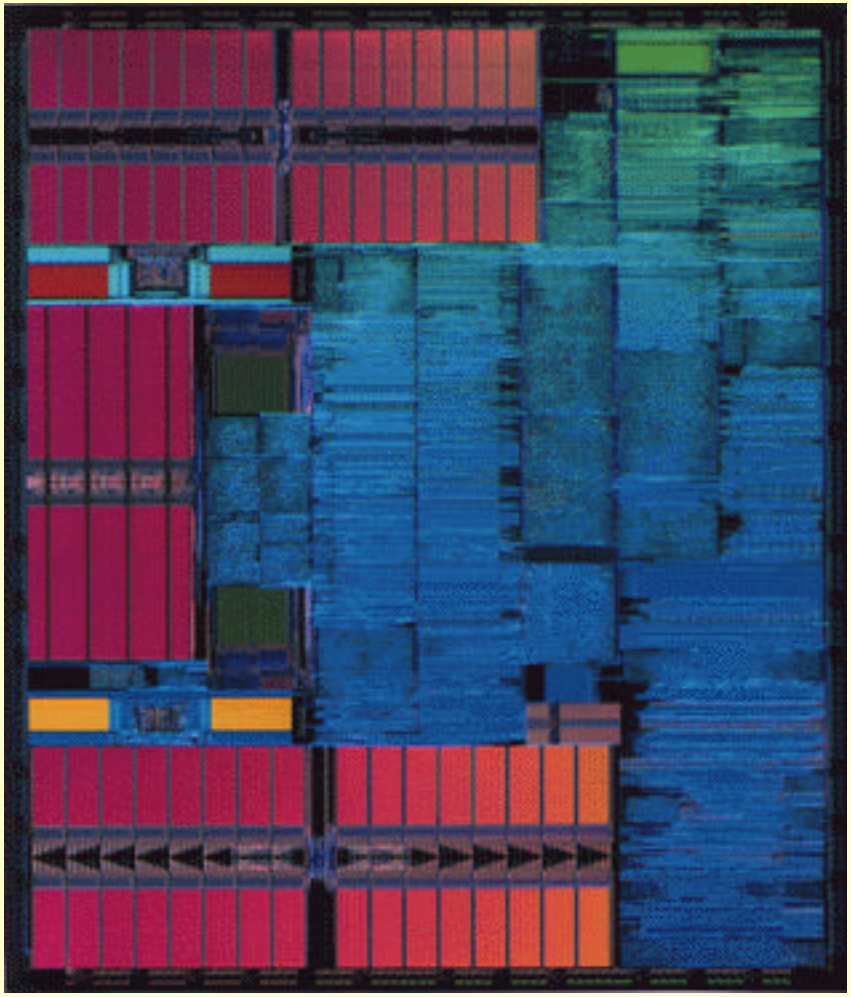
# Introduction to X2000

## X2000 First Delivery

- General
  - Scalable, modular, long life
  - Radiation hardened designs, parts, & materials
  - Sensor/Instrument input and output
- Avionics
  - Computer, local memory, mass memory
  - Power & pyro switching
  - Power system control
- Communications
  - Spacecraft transponding modem (STM) with X and Ka-band capabilities
- Flight and Ground software (MDS)
  - Operating systems
  - Generic auto-nav, 3-axis attitude control
  - Generic flight/ground autonomy
  - Generic flight/ground science data processing
  - Generic ground command/telemetry processing & display
- Advanced Radioisotope Power System (ARPS)
- High efficiency 0.9N thruster

# Introduction to X2000

## A 240 MIPS Flight Computer

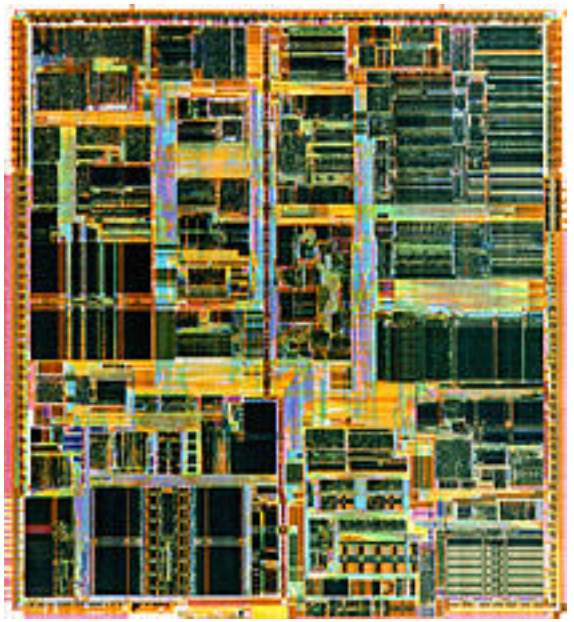


- **X2000 First Delivery will include a complete flight computer system based on a new 1 MRAD hard version of the Motorola 750 *PowerPC*® processor (the G3 chip.)**

# Introduction to X2000

## The Space Pentium®

- In December, Intel announced it was giving the rights to the Pentium® processor to the US Government for use in space and defense applications
- Sandia National Laboratory will space-qualify the chip
- JPL will insure that the finished chip supports a space computer system that is low power and radiation hard
- The finished space Pentium® is expected in 2002

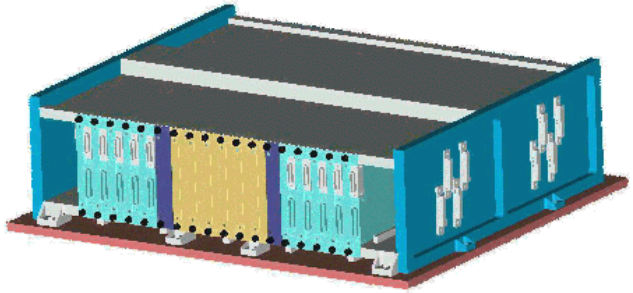



The X2000 Program

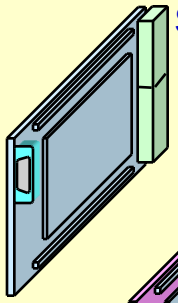
# Introduction to X2000

## Avionics Building Blocks – 9 Slices to Mix and Match

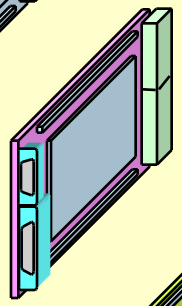
- X2000 avionics is being built in slices based on CPCI
- The system is plug-and-play
- PCI and IEEE 1394 buses



### Command and Data Handling Slices

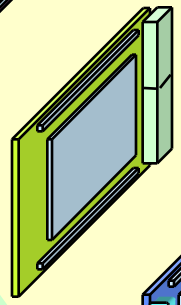


**SFC - System Flight Computer**
- PCI based
- Baseline 100 MIPs

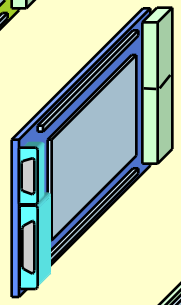


**SIO - System Input/Output**
- PCI/1394/$I^2C$ Bridge

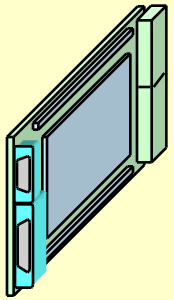
"Flight Computer" Slices



**NVM - Non Volatile Memory**
- 1 Gbit/slice Flash Memory

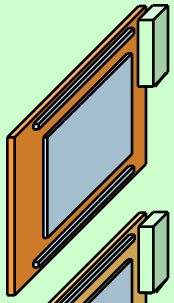


**MCS - Microcontroller Slice**
- General purpose controller for spacecraft peripherals

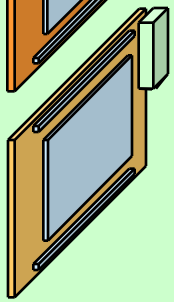


**SIF - Transponder Interface**
- Cross straps to two transponders

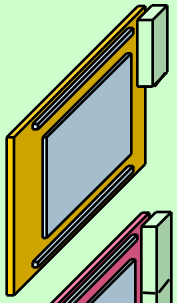
### Power Subsystem Electronics Slices



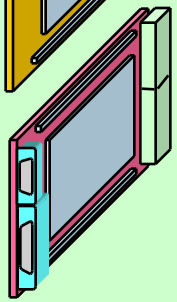
**BCS - Battery Charge Slice**
- Li-ion battery control



**PCS - Power Control Slice**
- Primary power bus regulation
- Shunt regulator



**PCA - Power Converter**
- Primary to secondary power conversion
- 10W or 30W versions

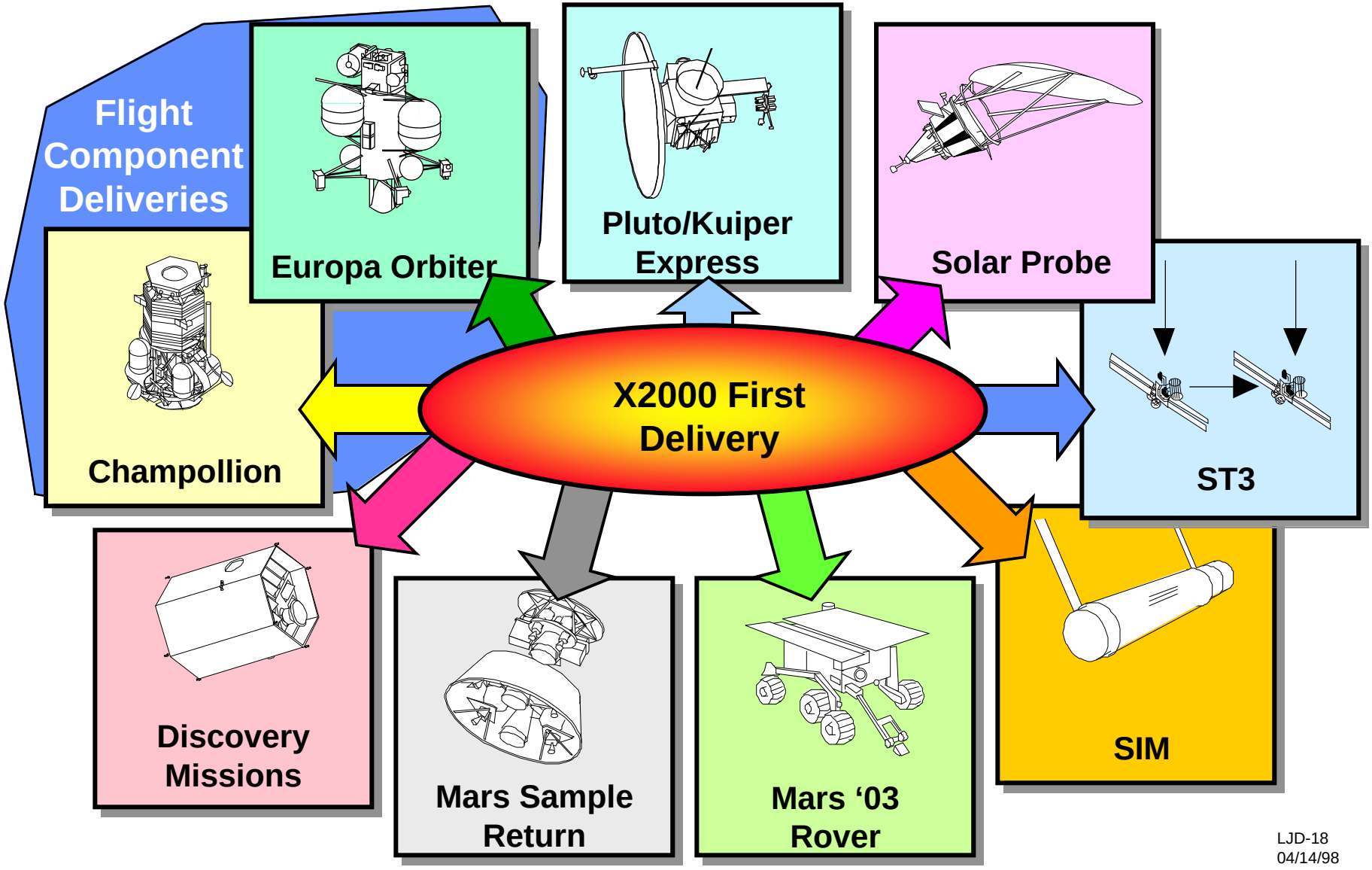


**PSS - Power Switch Slice**
- Switch power loads, valves & pyros
- 24 switches/slice
- Software bypass safety inhibits

The X2000 Program

# Introduction to X2000

## Customers for X2000 First Delivery

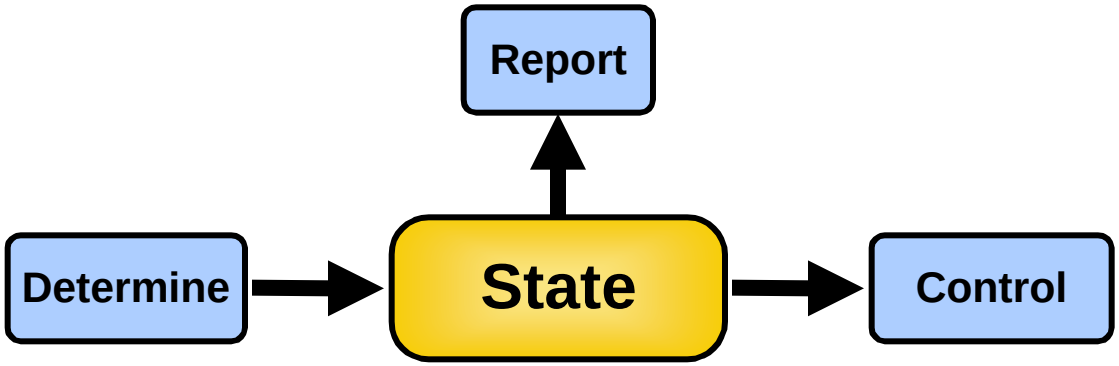



LJD-18
04/14/98

# Introduction to X2000

## The Mission Data System (MDS)

- The MDS is the glue that holds X2000 together
  - Includes all flight and ground software required to provide delivered functionality
  - Embodies the end-to-end system architecture
- "State" is the central concept of the MDS
- The MDS provides the framework for advanced autonomy, distributed throughout a large end-to-end system
  - Including operation of fleets of cooperating spacecraft



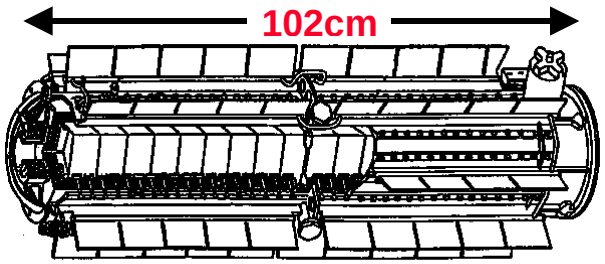

The X2000 Program

# Introduction to X2000

## Advanced Radioisotope Power System (ARPS)

- **X2000 is developing, in partnership with DoE, an advanced, highly efficient radioisotope power system that dramatically reduces the use of radioactive material for U.S. space missions – will be part of X2000 First Delivery**

**Today:**

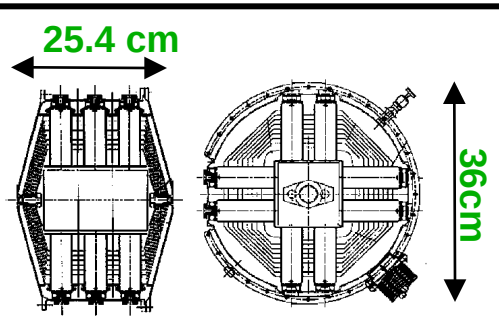



One of three Cassini Radioisotope Thermoelectric Generators (RTGs)

**CASSINI RTGs:**
Power = 855 watts
Mass = 168 kg
$PuO_2$ Mass = 32.4 kg
$Pu^{238}$ Mass = 23.4 kg

X2000/ARPS

**Future:**

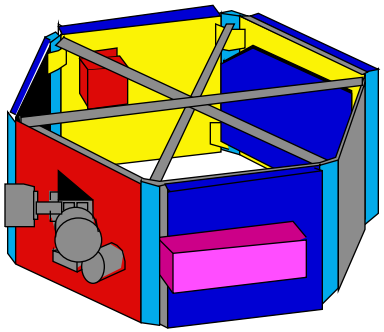

One ARPS per Outer Planets/Solar Probe missions

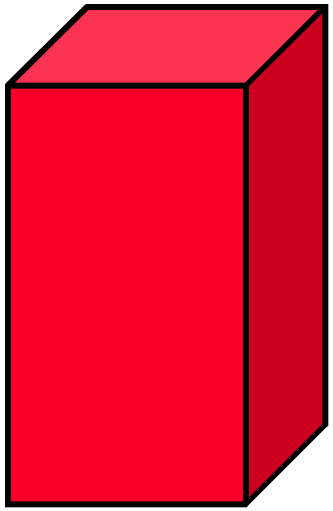
**OP/SP ARPS:**
Power =150 watts
Mass = 16 kg
$PuO_2$ Mass = 3.0 kg
$Pu^{238}$ Mass = 2.2 kg

LJD-20
04/14/98

# Introduction to X2000

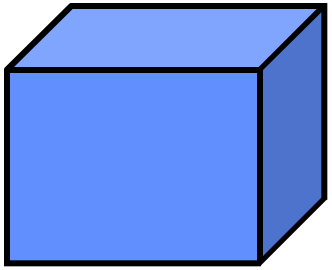
## Center for Integrated Space Microsystems (CISM)





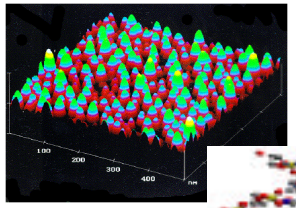
### 1st Delivery Electronics

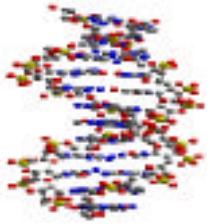
- Power electronics
- Telecom processing
- 3D multichip module standard
- Integrated architecture



### Avionics System-on-a-Chip

- Begin design and fabrication of minimum avionics system-on-a-chip.
- Telecom, power management, CPU, memory, and sensors.





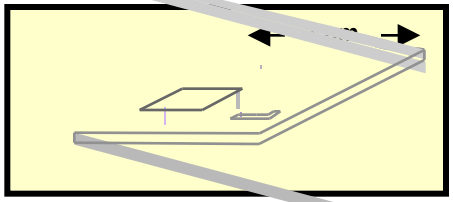
### Revolutionary Computing

- Reconfigurable computing
- Ultra-low-power electronics
- Quantum computing
- MEMS-Optics, etc.

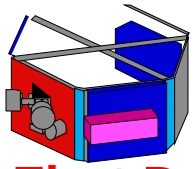
The X2000 Program

# Introduction to X2000

## System on a Chip (SOAC)

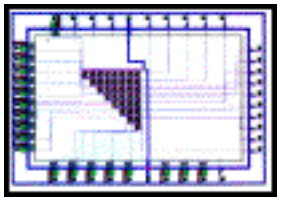


Micromachined front end for miniaturized RF comm

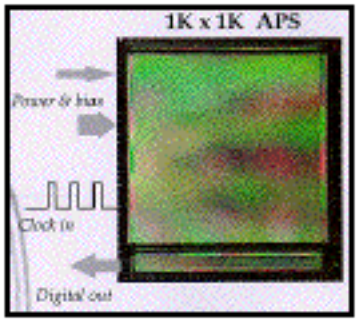


**X2000 First Delivery:**

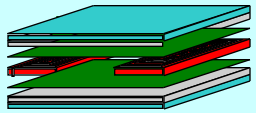
~10,000cc, ~60 kg, ~150W



Ultra-low-power architecture & devices

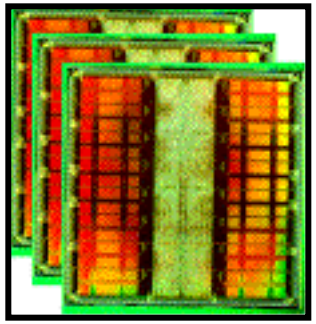



Active Pixel Sensors for low-power optical comm & star trackers

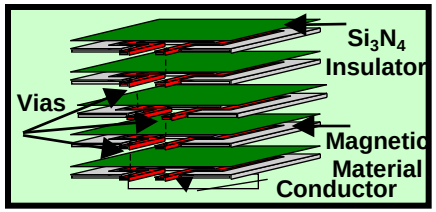


**SOAC:**

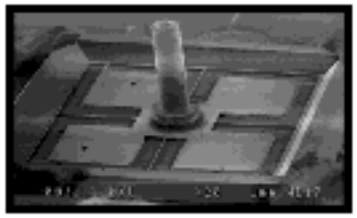
<100cc, <1 kg, ~ 30 -50W



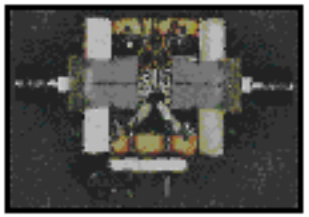
Processor in memory



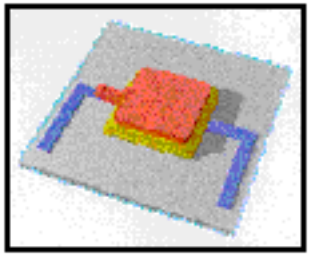

Thin film microtransformers for power management



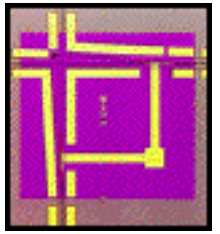
MEMS inertial reference system



Thermoelectric thin film coolers



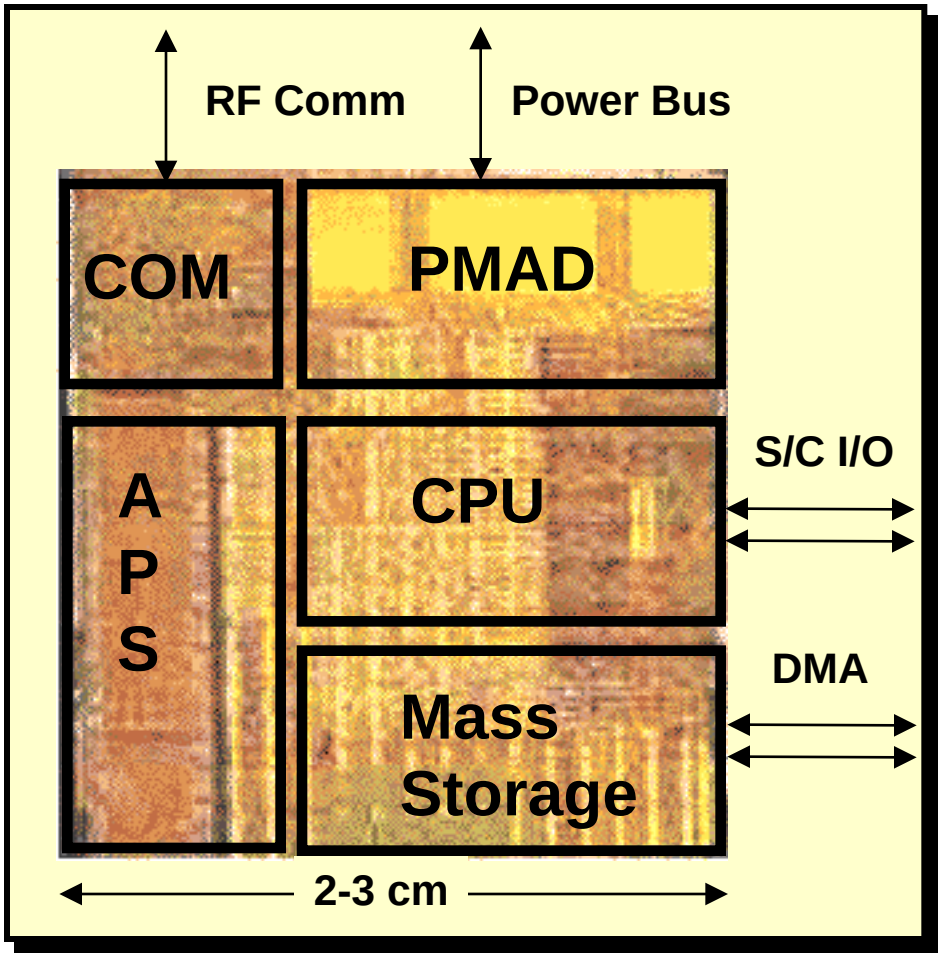
Thin film batteries for on-chip power



# Introduction to X2000

## System-on-a-Chip (SOAC) Vision

- **Highly capable, autonomous avionics system which includes CPU, mass memory, power management and distribution, telecomm, and sensors; all integrated into a monolithic unit.**
- **Benefits:**
  - **Volume/Mass reduction**
  - **Improved performance and reliability**
  - **Power reduction**



# Introduction to X2000

## Radio Frequency (RF) Front End

- Work performed in collaboration with the University of Michigan
- Fabricated a high isolation switch prototype
- Developed new fabrication process for filters
- Designed the high power SiGe HBT

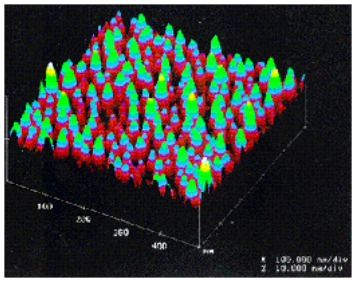
SiGe 3-stage amplifier

RF switch

The X2000 Program

# Introduction to X2000

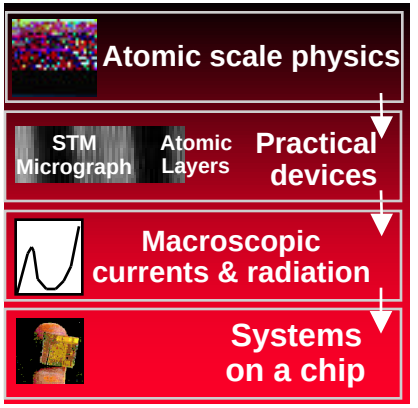
## Revolutionary Computing Technologies



Quantum Dots

Quantum Computing

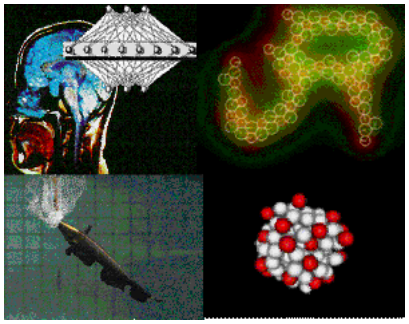
Optical Computing



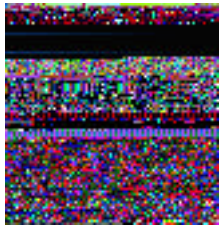

Nano-technology Modeling

**"Mission - inspiring"**

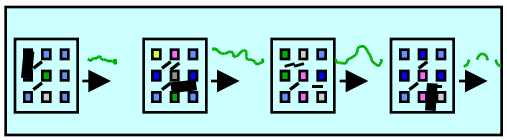
Breakthrough Revolutionary Computing Technologies & Architectures



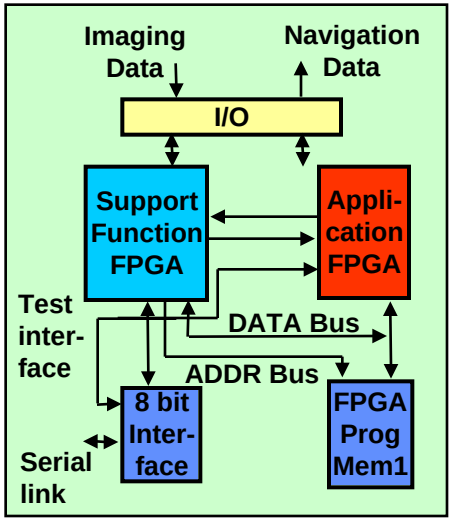
Biological Computing



DNA Computing



Evolvable Hardware




Reconfigurable Computing

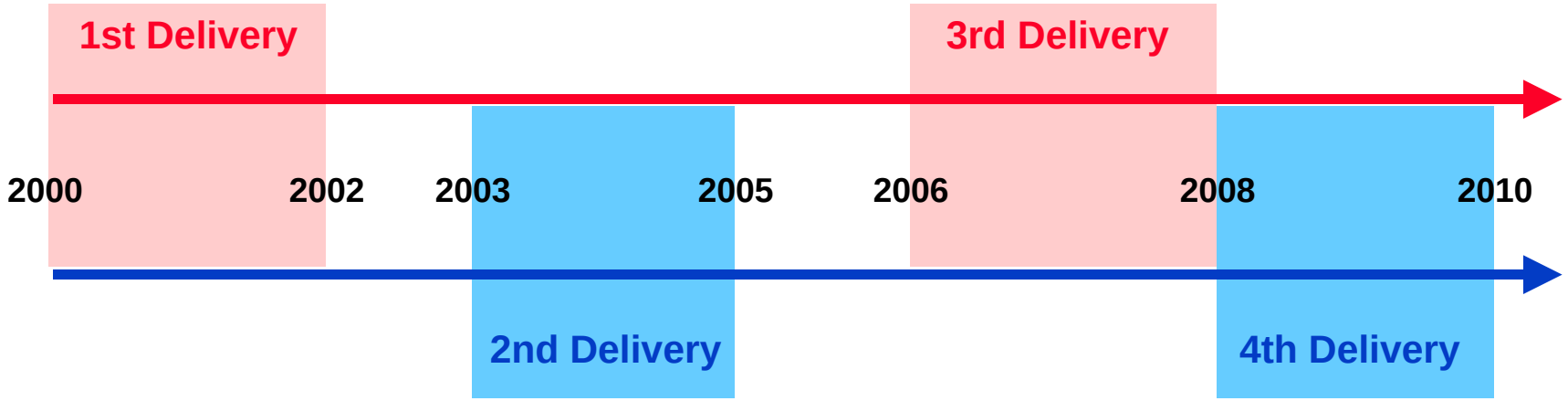
# Introduction to X2000

## X2000 Future Deliveries Vision

- **On 4-6 year centers, revolutionize the *remote sensing, full spacecraft* capability.**
- **In between these deliveries, enable *new systems* for new exploration approaches and provide a path for progress towards the next revolution.**

***sharpening*** **capabilities (orbiters, flybys, probe carriers, landers, ...),**

***broadening*** **the exploration toolset (penetrators, aerobots, subsurface systems, ...)**



The X2000 Program

# Introduction to X2000

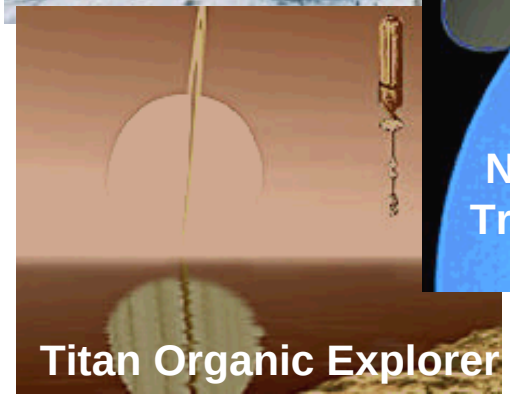
## Future Deliveries: Develop Technology for Strategic NASA Missions

**Need advanced capabilities in many diverse systems:**
**Orbiters, landers, probes, rovers, penetrators, aerobots, aircraft, sub-surface, submarine, …?**



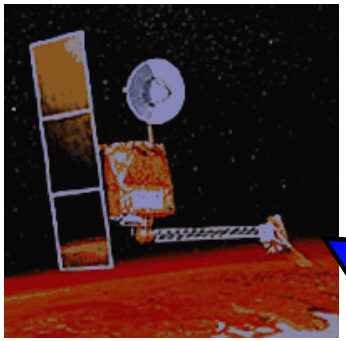






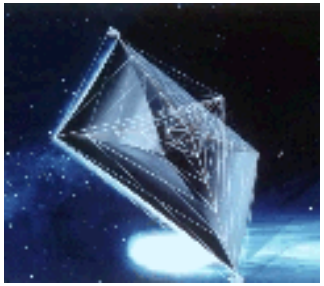

# Introduction to X2000

## Some Possible Second Delivery Beneficiaries

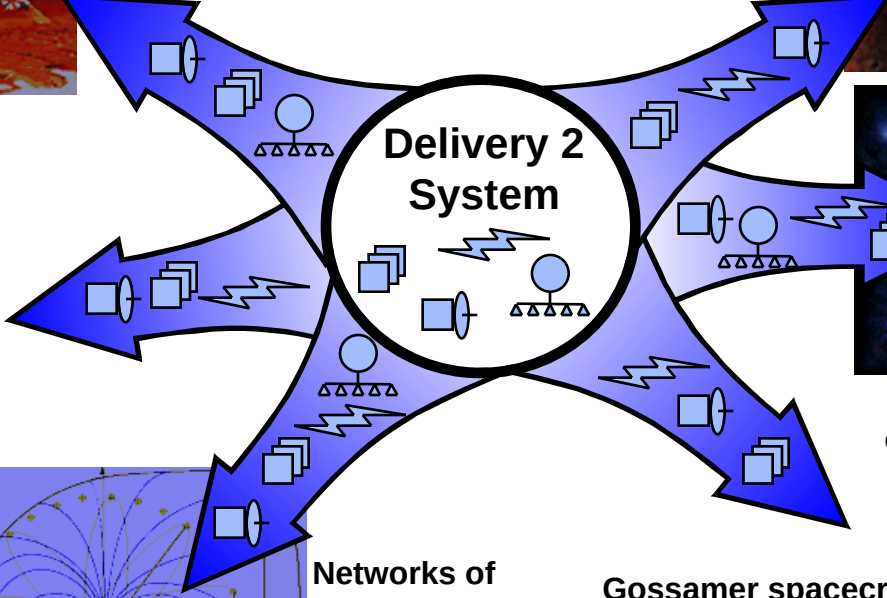


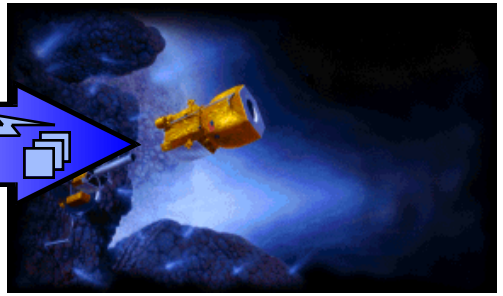
Mars Micro-Mission Carriers or Science Platforms

Aerobots, rovers, and other small platforms

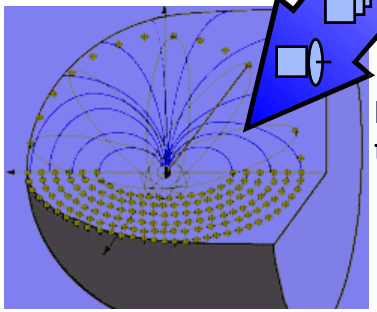


Interstellar Precursor (Solar Sail Demos)



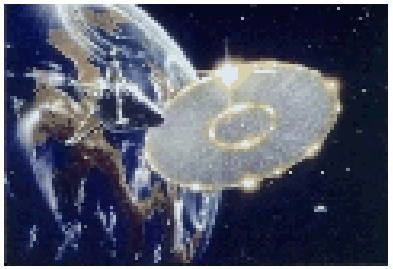



Daughter spacecraft or other separable payloads



Networks of tiny spacecraft

Gossamer spacecraft; large lightweight structures with distributed functions in small nodes.

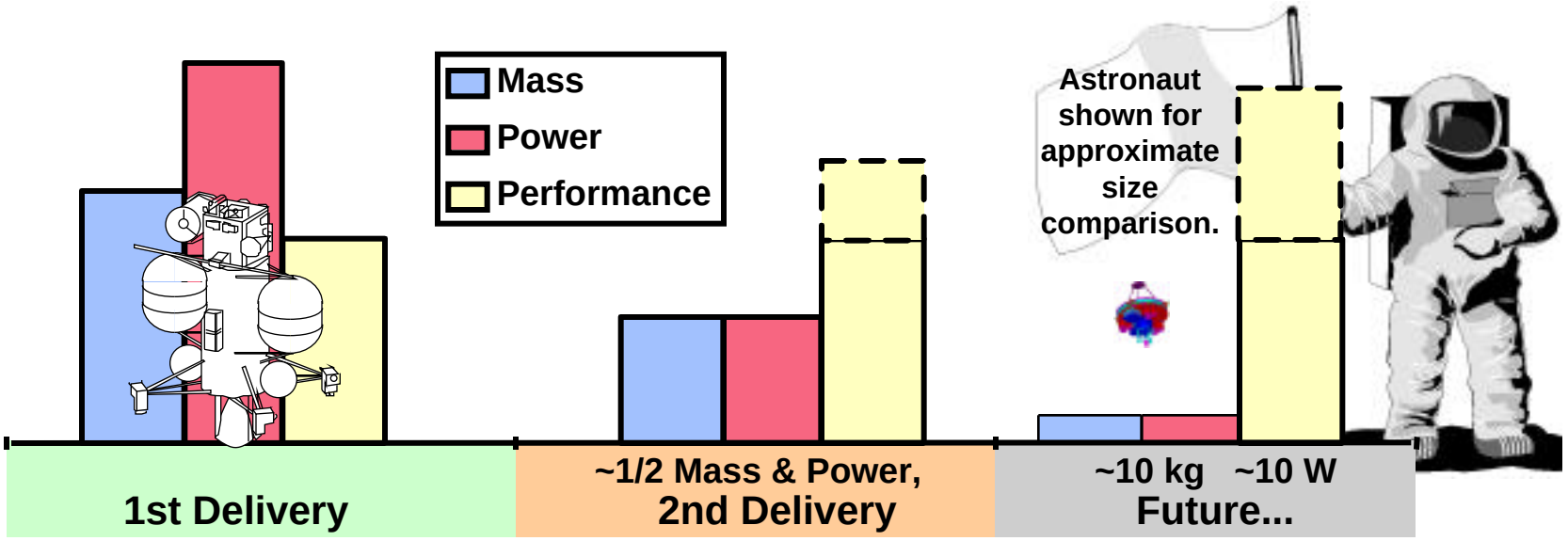


= Integrated Avionics  / = Deep Space/Relay Communications  = Mini Propulsion

# Introduction to X2000

## Conclusion

- NASA's X2000 Program is important for two reasons
  - It develops technology that enables new types of space exploration
  - It is a new, faster and cheaper process for technology infusion
  - It transfers these capabilities to US industry so they are available for future spacecraft
- Many of these new capabilities are relevant to Earth missions as well
- X2000 will work with the NASA Goddard Space Flight Center (and others) to help make these capabilities available to a larger community




... while maintaining low recurring cost

# Introduction to X2000

## Program Vision for Spacecraft Capabilities Growth

| | ~1997 | 1st Delivery | 2nd Delivery | 3rd Delivery |
|---|---|---|---|---|
| Avionics Mass | ???? (Pathfinder) | 50kg | 5kg | 1kg |
| Avionics Cost | ~$40M (Pathfinder) | $15M | $8M | $5M? |
| Plutonium Bricks | 54 (Cassini) | 8 | – | 1 |
| Processor MIPS | ~12 (Pathfinder) | ~150 | ~200 | ~1000 (RCT) |
| Mission Unique SW | 90% (Pathfinder) | 50% | 30% | 30% |
| Autonomy | High Level Commands (Pathfinder) | Goal-Achieving | Science Assist | Cooperative Behavior |
| Time for Infusion | 3 years (Pathfinder) | 2 years | 1 year | 6 months |
| Ops Team | ~60 (Cassini) | ~8 | ~5 | 1? |

# Introduction to X2000

## Success of DSST – How Will We Know?

- We are successful if our customers are successful
  - New technology does no good if it is not used
  - Our customers cannot accomplish their goals without new technology
  - The success of our first customers, ST4 and Europa Orbiter, are critical to the success of the program: but to be truly successful, DSST must learn to think beyond the current delivery at all times
- We are successful if NASA succeeds in being able to do many missions for a lot less cost
- We are successful if we truly go out and answer the basic, burning questions about the Earth, the solar system, and the universe